A Flux Scaling Scenario and Plateau Inflation

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After BICEP2 our group tried to concretely realize F-term single field axion monodromy inflation [Marchesano et al; Hebecker et al.; Blumenhagen et al.]. We need a single light axion Θ as inflaton and the following hierarchy where all scales differ by only $\mathcal{O}(10)$: [e.g. Baumann, McAllister]

$$M_{Pl} > M_s > M_{KK} > V_{inf} \sim M_{mod} > H_{inf} > M_\Theta$$

But:

- Kähler moduli not included in the analysis.
- The Kähler moduli are usually stabilized by subleading instanton effects $\Rightarrow$ exponential hierarchies.
- No sign of susy at the LHC.

Contemplate about tree level stabilization of all moduli with only polynomial hierarchies!

Possible solution: Use geometric AND non-geometric fluxes.
$\Rightarrow$ All moduli appear at tree level in a polynomial superpotential:

$$W = -\big(\mathfrak{f}_\lambda X^\lambda - \tilde{\mathfrak{f}}^\lambda F_\lambda\big) + iS\big(h_\lambda X^\lambda - \tilde{h}^\lambda F_\lambda\big) + iT_\alpha\big(q_\lambda{}^\alpha X^\lambda - \tilde{q}^{\lambda\alpha} F_\lambda\big)\,.$$

We searched systematically for vacua with the following properties

- non-supersymmetric
- tachyon free
- moduli in perturbative regime (weak coupling, large radius)
- all saxions stabilized

A representative toymodel

Imagine a isotropic torus with fixed complex structure, therefore $h^+_{11} = 1$, $h^-_{21} = h^-_{11} = 0$ and the Kähler potential

$$K = -3\log(T + \bar{T}) - \log(S + \bar{S})\,.$$

Choose the follwing superpotential

$$W = -i\tilde{\mathfrak{f}} + ihS + iqT\,.$$

Look at susy minimum $0 = \mathcal{D}_i W$ (Recall $S = s + ic,\ T = \tau + i\rho$)

$$ihs, iq\tau \sim W \quad \text{and} \quad q\rho + hc = 0.$$

$\Rightarrow$ Each term scales individually as W which has to scale as $W \sim \tilde{\mathfrak{f}}$
$\Rightarrow$ From this one can read off $s \sim \frac{\tilde{\mathfrak{f}}}{h}$ and $\tau \sim \frac{\tilde{\mathfrak{f}}}{q}$

The same relations hold for all extrema!

Common properties of the flux scaling vacua

Overall scaling of W (e.g. $W \sim \tilde{\mathfrak{f}}$). This fixes the scalings

- of the moduli $s \sim \frac{\tilde{\mathfrak{f}}}{h}$ and $\tau \sim \frac{\tilde{\mathfrak{f}}}{q}$,
- the negative cosmological constant $V \sim e^K |W|^2 \sim -\frac{hq^3}{\tilde{\mathfrak{f}}^2}$,
- the masses $m_{mod} \sim m_{\frac{3}{2}} \sim (\partial\partial K)^{-1}\partial\partial V \sim \frac{hq^3}{\tilde{\mathfrak{f}}^2}$,
- the string scale $m_s \sim s^{-\frac{1}{4}}\mathcal{V}^{-\frac{1}{2}} \sim \frac{h^{\frac{1}{4}} q^{\frac{3}{4}}}{\tilde{\mathfrak{f}}}$,
- the KK scale $m_{KK} \sim \mathcal{V}^{-\frac{2}{3}} \sim \frac{q}{\tilde{\mathfrak{f}}}$

$\Rightarrow$ All relevant quantities are determined.

$\Rightarrow$ Polynomial hierarchies between the scales, but no parametric hierarchy in the moduli masses.

$\Rightarrow$ Highscale SUSY $m_{mod} \sim m_{\frac{3}{2}}$

$\Rightarrow$ This behaviour is very generic, we collected many (more complicated) models.

mass scales from the string theory perspective

Recall: The saxions were $s_0 \sim \frac{\tilde{\mathfrak{f}}}{h}$ and $\tau_0 \sim \frac{\tilde{\mathfrak{f}}}{q}$ at the minimum.

- To be in perturbative regime we must demand $\tilde{\mathfrak{f}} \gg h, q$
- For $h > q$, α' corrections to K are subleading as $\tau > s$

We find

$$\frac{M_{KK}}{m_{moduli}} \approx 1.7 \frac{1}{\sqrt{\mu q h}} \quad \Rightarrow \quad M_{KK} \approx m_{moduli}$$

For some models the validity as a string effective action is not ensured. Nonetheless unambiguous gauged SUGRA.

But: Due to the easy scale relations we were also able to engineer models where the scales separate in the perturbative regime.

D-term tachyon uplift

Problem: Models with more moduli are often tachyonic.

We derived the Freed-Witten anomaly conditions for non-geometric fluxes. We used them to simplify the D-term potential of a D7 brane

$$V_D = \frac{M_{Pl}^4}{2Re(f)} \xi^2 \,, \qquad \xi = \frac{1}{\mathcal{V}} \int_\Sigma J \wedge c_1(L)$$

- The minima are not shifted by the D-term.
- The D-term gives a positive contribution precisely for the Kähler tachyons! The other masses are unaffected.

⇒ Non-trivial interplay between geometry and anomaly gives a uplift mechanism for Kähler tachyons (complex structure?)!

Other aspects

- We computed the soft masses of an MSSM on D7 branes. In general all masses are $\sim m_{\frac{3}{2}}$, but there are models where some F terms can be set to zero. Then a gravitino with an intermediate mass $m_{Gravitino} \ll m_{\frac{3}{2}}$ is possible.

- Recently, Brown, Cotrell, Shiu and Soler state that the tunneling rate between flux branches can be substantial. They assumed

$$H < V^{\frac{1}{4}} < M_{KK} < M_s < M_{Pl}$$

We have in general

$$V^{\frac{1}{4}} \sim M_s$$

which is problematic for inflation but leads to a exponential surpression of the tunneling rate in the perturbative regime.

Other aspects and unsolved questions

- The backreacted non-geometric geometry is unknown (Ongoing work)
- We verified that there is also no dilute flux limit for these vacua. The backreaction of the fluxes onto the geometry is therefore not under control.
- We found no sign of dS vacua [Blåbäck, Danielson, Dibitetto, Damian, Loaiza-Brito]
  We tried an uplift e.g. by a term

  $$V_{up} = \frac{\epsilon}{\mathcal{V}^{\alpha}}$$

  with e.g. $\alpha = 4/3$ or 2 for a brane in warped throat or a $\overline{D}3$-brane. Problem: We need a small $\alpha \leq 1/6$ to leave the vacuum stabilized. What could source this?

Inflation with flux scaling minima

Original task: Get parametrical control over an axions mass for large field axion inflation.

We were half successful:
We have control, but then the scales are problematic.

Here: A qualitative picture how inflation looks for different mass hierarchies. We uplift the potential to $V_0 = 0$ and look at the backreacted potential for a running axionic inflaton Θ.

Qualitative picture of inflation

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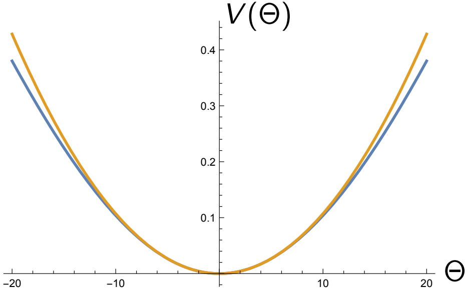
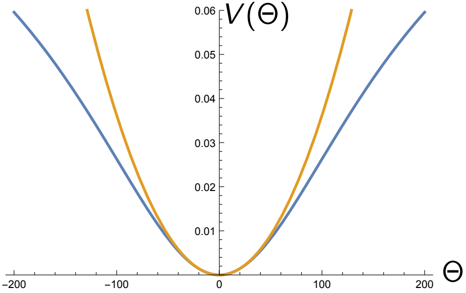
For a large hierarchy e.g. 60 only $m_\theta < H$ and thus single field inflation. The quadratic approximation holds long enough for 60 e-folds $\Rightarrow r \sim 0.133$.



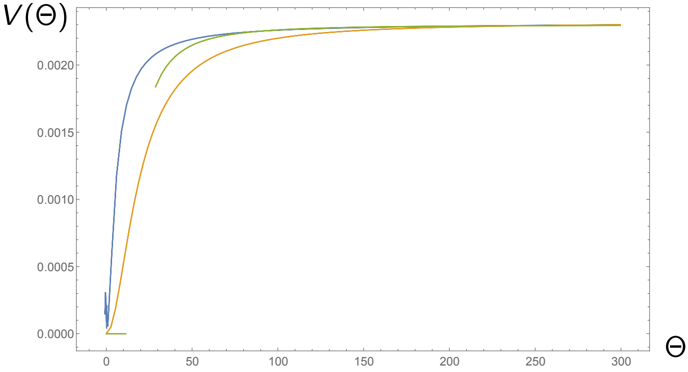
Orange is the quadratic approximation, blue is the exact potential.

For a lower mass hierarchy of ~ 10 still only $m_\theta < H$ but the backreaction leads to a substantial flattening giving rather linear inflation $\Rightarrow$ Smaller tensor-to-scalar ratio of $r \sim 0.08$.



Orange is the quadratic approximation and blue is the true potential.

No mass hierarchy $\lambda = 1$ means $m_{moduli} \sim m_\Theta < H$ and we therefore have a multifield inflation. Backreaction so large that the e-folds are collected along a plateau $\Rightarrow r \approx 0.003$!



Blue is the multifield inflationary trajectory and green an approximation of Starobinski like form $V(\Theta) = A - Be^{-\gamma\Theta}$. Orange a single field approximation to see the transition from a quadratic to a linear to a plateau potential.

Conclusion

We performed a systematic search and analysis of non-susy minima in a gauged type IIB orientifold with geometric and non-geometric fluxes and had a qualitative look at inflation

- All moduli stabilized at tree level
- Polynomial superpotential leads to polynomial hierarchies
- Parametric control due to appearing flux scaling made it possible to engineer nice models
- Nice mechanism to uplift Kähler tachyons
- Non-geometric fluxes lead to problems with the KK-scale and the dilute flux limit from the string theory perspective.
- Axionic inflation interpolates between quadratic, linear and plateau inflation depending on the mass hierarchy.